JPL PUBLICATION 79-97

Climatological Relationships of Severe Duststorms in the Great Plains to Synoptic Weather Patterns: A Potential for Predictability

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SUBJECT: Errata

Gentlemen:

Please note the following corrections to JPL Publication 79-97, Climatological Relationships of Severe Duststorms in the Great Plains to Synoptic Weather Patterns: A Potential for Predictability, by John F. Henz and Peter M. Woiceshyn, dated November 15, 1979.

Cover and title page:	add "Denver, Colorado" to "Geophysical Research and Development Corporation"
p. 6-1:	change author of last entry to read, "Woiceshyn, P. M."

Very truly yours,

John W. Kempton, Manager
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FOREWORD

This document was originally published as Jet Propulsion Laboratory internal document No. 900-917. A broader interest in this subject warranted distribution in its present form as a Jet Propulsion Laboratory external document.

ACKNOWLEDGMENT

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DEFINITION OF ACRONYMS/NOMENCLATURE

CSI	critical success index
CY	cyclone, cyclonic
D	duststorm
FT	frontal, front
GMT	Greenwich mean time
GOES	geostationary orbital environmental satellite
GRD	geophysical research and development
GRDC	Geophysical Research and Development Corporation
hr	hour
JPL	Jet Propulsion Laboratory
K	CSI constant
kt	knot
km	kilometer
LFM	limited (area) fine mesh
LFM-I	LFM, model I
LLJ	low level jet (850 mb)
m	meter
mb	millibar
mps	meter per second
ND	no duststorm
NMC	National Meteorological Center
NOAA	National Oceanographic and Atmospheric Administration
P	pressure
PE	primitive equation
PIREPS	pilot reports

prog	prognostic chart
RAOBS	radiosonde observations
SCS	Soil Conservation Service
SDW	severe downslope windstorm
sfc	surface
SMDW	severe mountain downslope windstorm
T	temperature
ULJ	upper level jet (500 mb)
USDA	United States Department of Agriculture

ABSTRACT

A data base provided by 35 severe duststorms that occurred between 1968 and 1977 in the central and southern Great Plains allowed construction of a classification scheme of meteorological causes of duststorms, and a "telescopic forecast technique" for medium-range (6- to 48-hour) prediction of severe cyclogenic duststorms. In addition, areal coverage definitions for duststorms based on characteristics of the storms, and a hierarchy of weather causes of severe duststorms were developed. The man-machine-mix forecast correctly predicted six of seven duststorms observed during the 1976 - 77 winter, with one overforecast; the machine-only forecast correctly predicted four of the seven duststorms, with one overforecast. Both techniques had problems correctly predicting the duration of severe duststorms.

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SECTION I

INTRODUCTION

Drought cycles and accompanying periods of severe soil erosion have occurred on the Great Plains at 20-year intervals since the 1930s. Figure 1-1 identifies the Plains regions which have been affected by major droughts. The recent drought of the 1970s has stimulated a renewed interest in the short-range predictability of severe duststorm episodes. The Soil Conservation Service (SCS) of the United States Department of Agriculture (USDA) reported nearly 6.8 million acres of Plains land were stripped of topsoil during 1977.

The ability to anticipate the occurrence of duststorms on both a seasonal and short-term basis would provide agriculture with a potential means of reducing the loss of topsoil through various soil protection practices.

This report presents the results of a study on the short-range predictability of severe duststorms in the central and southern portions (Figure 1-1 stippled area) of the Great Plains. A data base of 35 duststorms occurring from 1968-77 was investigated. A classification scheme of meteorological causes of duststorms is proposed and examples of dominant causes are presented. A "telescopic forecast technique" developed for the medium-range (6-48 hour) prediction of severe cyclogenic duststorms is presented. Results of an initial attempt at duststorm predictions during the winter of 1976-77 are discussed. Verification statistics are presented and interpreted.

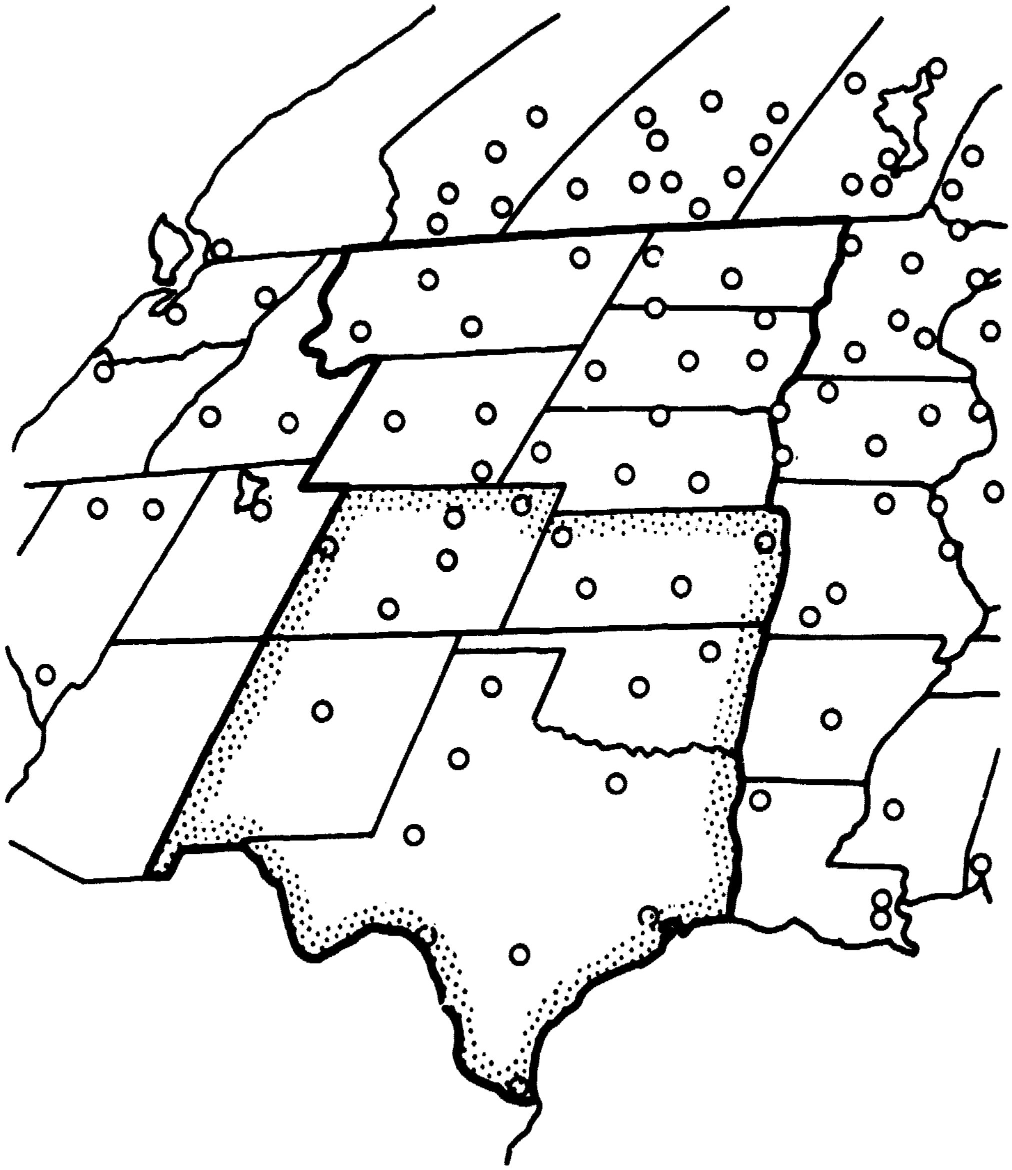

Figure 1-1. Location of the Great Plains Duststorm Region with Study Area Indicated by Stippled Boundary

SECTION II

SEVERE DUSTSTORM SURVEY

Only very sparse information is readily available on duststorm occurrence on the Great Plains. A notable exception is the documentation presented by Fryrear and Randle, 1972, and Fryrear, 1975, for the Big Spring, Texas, locale. A summary of west Texas regional "dusty days" based on observations of dust at six locations for the period 1970-76 is presented in Table 2-1. Considerable annual variation is apparent from month to month. The spring months of March and April are generally stormy and were, as expected, the "dustiest." The table data confirms the seasonal nature of the prediction problem in west Texas.

A study of significant duststorm occurrences reported in the NOAA publication, Storm Data, was completed for the ten-year period 1968-77 for the states of Colorado, Kansas, New Mexico, Oklahoma, and Texas. Table 2-2 presents a listing of the duststorms reported, the states affected, and the probable synoptic-scale weather cause. It is interesting to note the increase in the number of reported widespread duststorms in this region during the severe drought period of the mid-1970s.

This table should not be considered as an all-inclusive listing of major duststorms. Storm Data's primary function is to serve as a reference documenting the occurrence of tornadoes, windstorms, hailstorms, flash floods, and other severe weather events. As a result, it is very likely that most moderate and even a few severe duststorm events, were unreported. Nonetheless, the severe duststorm dates obtained provided a reasonable sample (54 days) which could be researched.

The annual and monthly variations in the number of severe duststorm days are summarized in Table 2-3. Fifty-four severe duststorm days were identified as associated with thirty-five separate severe duststorm episodes. The months January through April produced 80 percent of the occurrences. The dustiest year of the ten-year period was 1975.

Monthly variations in the synoptic causes of the severe duststorms are summarized in Table 2-4. Frontal duststorms were reported most frequently from November to January while severe mountain downslope windstorms were reported most frequently from January to April. Cyclogenic duststorms occurred in an even distribution, although the March and April spring months were favored slightly. A more complete discussion of these synoptic duststorm causes will be covered in the next section.

Some additional results which are noteworthy are listed as follows:

(1) Of the 35 severe duststorm episodes, 20 episodes affected a one-state area. Of these episodes, 75 percent were caused by SMDW with the remainder related to frontal passages.

(2) Of the 15 multistate severe duststorms, 60 percent were caused by cyclogenic storms and the remainder by frontal passages.

Table 2-1. Number of Days with Blowing Dust Reports in Texas at Lubbock, Midland, Shepherd, Abilene, San Antonio, Dallas, and El Paso at First Order National Weather Service Stations from 1970 to 1975[a]

Year	Month														
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total[b]	Mean[b]	σ[c]
1970	2	4	4	9	5	4	0	0	2	0	0	5	35	2.9	2.8
1971	5	14	18	18	6	2	1	0	0	1	0	2	67	5.6	7.0
1972	2	2	9	11	5	2	1	0	0	1	0	2	35	2.9	3.6
1973	3	1	5	5	3	2	0	0	0	0	4	3	26	2.2	1.9
1974	5	9	6	14	5	4	3	0	0	0	0	1	47	3.9	4.3
1975	8	1	11	8	0	0	0	0	0	0	3	3	34	2.8	4.0
Total[d]	25	31	53	65	24	14	5	0	2	2	7	16	244	20.3	23.6
Mean[d]	4.2	5.2	8.8	10.8	4.0	2.3	0.8	0	0.3	0.3	1.2	2.7	40.7	3.4	3.9
σ[c]	2.3	5.3	5.2	4.6	2.2	1.5	1.2	0	0.8	0.5	1.8	1.4	14.5	1.2	1.7

[a]Woiceshyn, 1977.
[b]For the year
[c]Standard deviation.
[d]For the month.

Table 2-2. A Listing of Memorable Central and Southern Great Plains Duststorms 1968-77[a]

Year Date	States Affected					Probable Synoptic Weather Cause
	CO	KS	TX	OK	NM	
1968						
Feb 2-4	X					SDW[b]
Dec 4	X					SDW
Dec 11-14	X	X				FT[c]
1969						
Jan 7-8	X	X				FT
Jan 31	X					SDW
Mar 19	X					SDW
Apr 6-7	X					SDW
1970						
Jan 24-25	X					SDW
Feb 3	X					SDW
Mar 24	X					SDW
Apr 14	X					SDW
Nov 30	X	X				FT
Dec 3		X				FT
Dec 15			X			FT
1971						
Feb 3-4			X			FT
Mar 17-18	X	X		X		CY[d]
1972						
Jan 11-12	X	X	X	X	X	CY
Apr 12	X					SDW
Dec 5			X		X	CY
1973						
Apr 18-19	X	X	X	X		CY
May 27	X	X		X		CY
1974						
Mar 2	X					SDW

Table 2-2. A Listing of Memorable Central and Southern Great Plains Duststorms 1968-77[a] (Continuation 1)

Year Date	States Affected					Probable Synoptic Weather Cause
	CO	KS	TX	OK	NM	
1975						
Jan 18-19	X			X		FT
Mar 22-23	X					FT
Apr 7-8	X					SDW
Apr 8			X			FT
Apr 27-28	X	X	X	X	X	CY
Oct 22	X					SDW
Nov 19		X	X	X		FT
Nov 29			X	X		FT
1976						
Jan 30	X					SDW
Feb 17-18	X					SDW
1977						
Feb 22-23	X	X	X	X	X	CY
Mar 10-12	X	X	X	X	X	CY
Mar 17			X			FT

[a]As listed in the NOAA Storm Data 1968-77.

[b]Severe downslope windstorm.

[c]Frontal.

[d]Cyclone.

Table 2-3. Annual and Monthly Summary of Severe Duststorm Days as Listed in NOAA Storm Data 1968-77

Year	Jan	Feb	Mar	Apr	May	Jun-Sep	Oct	Nov	Dec	Annual Total
1968		3				a			5	8
1969	3		1	2		a				6
1970	2	1	1	1		a		1	2	8
1971		2	2			a				4
1972	2			1		a			1	4
1973				2	1	a				3
1974				1		a				1
1975	2		2	4		a	1	2		11
1976	1	2				a				3
1977		2	4			a	b	b	b	6
Monthly Total	10	10	10	11	1		1	3	8	54

[a]No duststorms in Jun-Sep period.

[b]Storm data missing or not available.

Table 2-4. Monthly Occurrences (1968-77) of Severe Duststorms and Appropriate Synoptic Weather Patterns

Synoptic Weather Cause	Jan	Feb	Mar	Apr	May	Oct	Nov	Dec
Cyclogenic	1	1	2	2	1			1
Frontal	2	1	2	1			3	3
Severe Mountain Down-slope Windstorm	3	3	3	4		1		1

(3) The average cyclogenic duststorm affected a four-state region over a period of approximately two days. An average frontal duststorm affected a two-state area for just more than a one-day period. SMDW duststorms affected a one-state region for varying periods of time.

These results suggest the following definitions of areal duststorm categories are reasonable:

(a) General duststorm - affects a region of not less than three states and normally at least four states over a period of two days or more.

(b) Localized duststorm - affects a region of two states or less during a period not exceeding one day.

(c) Micro-duststorm - affects a region of much less than one state in size (i.e., dust devils, haboobs, and tornadoes are examples).

By definition, cyclogenic duststorms are general duststorms in all cases; severe mountain downslope windstorm duststorms are localized duststorms in all cases (except when the SMDW is part of a large cyclogenic storm); and frontal duststorms may fall into either category. These definitions are based on the data sample of duststorms for 1968-77; and, as the sample size grows, refinements to these areal definitions will be made. Refinements related to the degree and severity of soil erosion produced by the duststorm were not attempted since consistent soil erosion figures for each of the states for the ten-year period were not available in a readily useable format.

SECTION III

WEATHER SYSTEMS AND DUSTSTORMS

A systematic investigation was made of the synoptic scale weather systems associated with the severe duststorm episodes previously listed in Table 2-2. A general classification scheme or hierarchy of the associated weather systems is proposed in Table 3-1. The genre, duststorm-producing weather mechanism, time frame and space scale, and predictability is presented for each of the weather systems. A discussion of each weather system with appropriate references and figures follows.

A. HABOOB

The haboob duststorm is a short duration weather system which is common in the semi-arid regions of the High Plains and the deserts of the southwest United States. Idso et al, 1972 describes the haboob in considerable detail. In general, the haboob is produced as the cool, moist air of a thunderstorm downdraft descends below the cloud base into a significantly drier layer of air. As the downdraft air moisture evaporates, the air is cooled causing its acceleration downward. Upon reaching the surface, the evaporatively cooled downdraft spreads out and lifts dust particles up from the desert floor several kilometers into the air. The physical appearance is similar to a huge dome of dust as presented in schematic form in Figure 3-1. Within the dust dome, surface wind velocities often exceed 25 mps and visibilities drop to near zero. The haboob typically does not produce severe erosion and occurs most frequently during the summer months June through August.

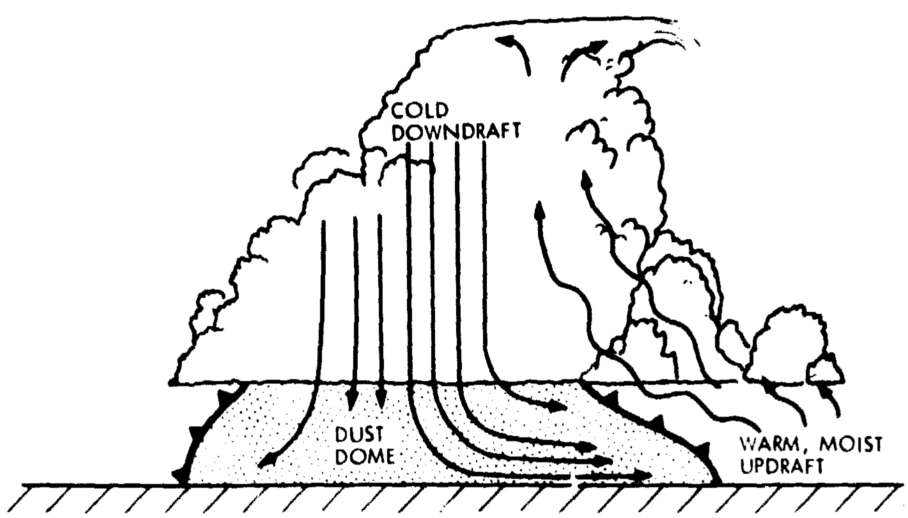

Figure 3-1. Diagram of a Typical High Plains Haboob Producing Thunderstorm

Table 3-1. Hierarchy of Weather-Duststorm Systems

	Genre	Mechanism	Time Frame (hr)	Space Scale (km)	Predictability
1.	Dust devil	Micro-temperature differences	0.1-0.5	0.01-0.50	Observe only in real time
2.	Haboob	Thunderstorm downdraft into dry air, i.e. gravity flow	0.5-6	25-75	1-12 hours
3.	Severe mountain downslope windstorm	Complex terrain enhancement of downward transport of mid-tropospheric momentum	0.5-18	25-250	12-36 hours
4.	Frontal	Gravity flow, pressure gradient with dynamic assist	1-8	500-1000	24-48 hours
5.	Cyclogenic				
a.	Low level jet	Boundary layer thermal differences, momentum transfer within shallow adiabatic plantary boundary layer	6-12	500-1000	24-48 hours
b.	Upper level jet	Deep adiabatic heating of troposphere through dynamic subsidence	8-24	500-1000	24-72 hours
c.	Surface storm circulation	Deeper-gradient winds	8-18	50-150	12-36 hours
d.	Severe mountain downslope windstorm	(Mechanism No. 3 above)			

B. SEVERE MOUNTAIN DOWNSLOPE WINDSTORMS

The severe mountain downslope windstorm is a short-to-moderate duration weather system which affects the immediate lee side of a mountain range, in this case, the High Plains. Henz et al, 1974, and Scheetz et al, 1976, describe the synoptic weather patterns and predictability of Colorado SMDW. These results are generally applicable to the lee-side regions of the High Plains from Montana to New Mexico.

A complex terrain enhancement of downward momentum transport from the mid-troposphere produces a 25-to-50 mile wide band of strong winds on the surface to the lee of the mountain range under special synoptic conditions. Because peak wind gusts often exceed 50 mps, severe erosion is occasionally produced by these storms. Figure 3-2 presents an illustration of the wave configuration, after Lily and Zipser, 1972, which produces a SMDW. This form of duststorm is frequently part of a larger cyclogenic duststorm.

C. FRONTAL DUSTSTORMS

Frontal duststorms are short-to-moderate in duration and are the most frequently observed cause of duststorms. In general, these duststorms are produced by intense surface pressure gradients and a dynamic coupling of mid-tropospheric momentum transfer into the boundary layer. In the case of polar fronts, a gravity flow or bora wind system best describes the dynamics which produce the excessive winds. It is not unusual for the entire High/Great Plains complex to be traversed by either a polar or Pacific frontal weather system. Dustblows usually develop along the leading edge of the front and persist for 1-4 hours after frontal passage. Along High Plains foothills regions, the duststorm conditions could persist for up to 8 hours.

Normally, a frontal duststorm will produce light-to-moderate soil erosion due to the short duration of high winds accompanying the front. Frontal precipitation also exerts a moderating effect on potential soil erosion. Frontal duststorms occasionally precede a period of rain or snow, especially in the case of a Canadian polar front.

The upper air pattern varies considerably for the two frontal duststorm types. In the case of the Canadian polar front, a deep amplitude trough is usually located over the Great Lakes while a high amplitude ridge is positioned along the Continental Divide. The duststorms occur along the leading edge of cold polar air outbreaks which plunge southward off the Canadian prairies at speeds of 20 mps or more. The more intense duststorms of this genre are supported aloft by a thermal short wave detectable at mid-tropospheric levels. A schematic of the Canadian or polar frontal duststorm is shown in Figure 3-3.

Pacific frontal duststorms are usually related to a strong zonal flow pattern over the United States. A fast moving mid-tropospheric short wave is associated with the front. The duststorm is normally located along the leading edge of the front and may extend 50-100 miles into the cold air (Figure 3-4).

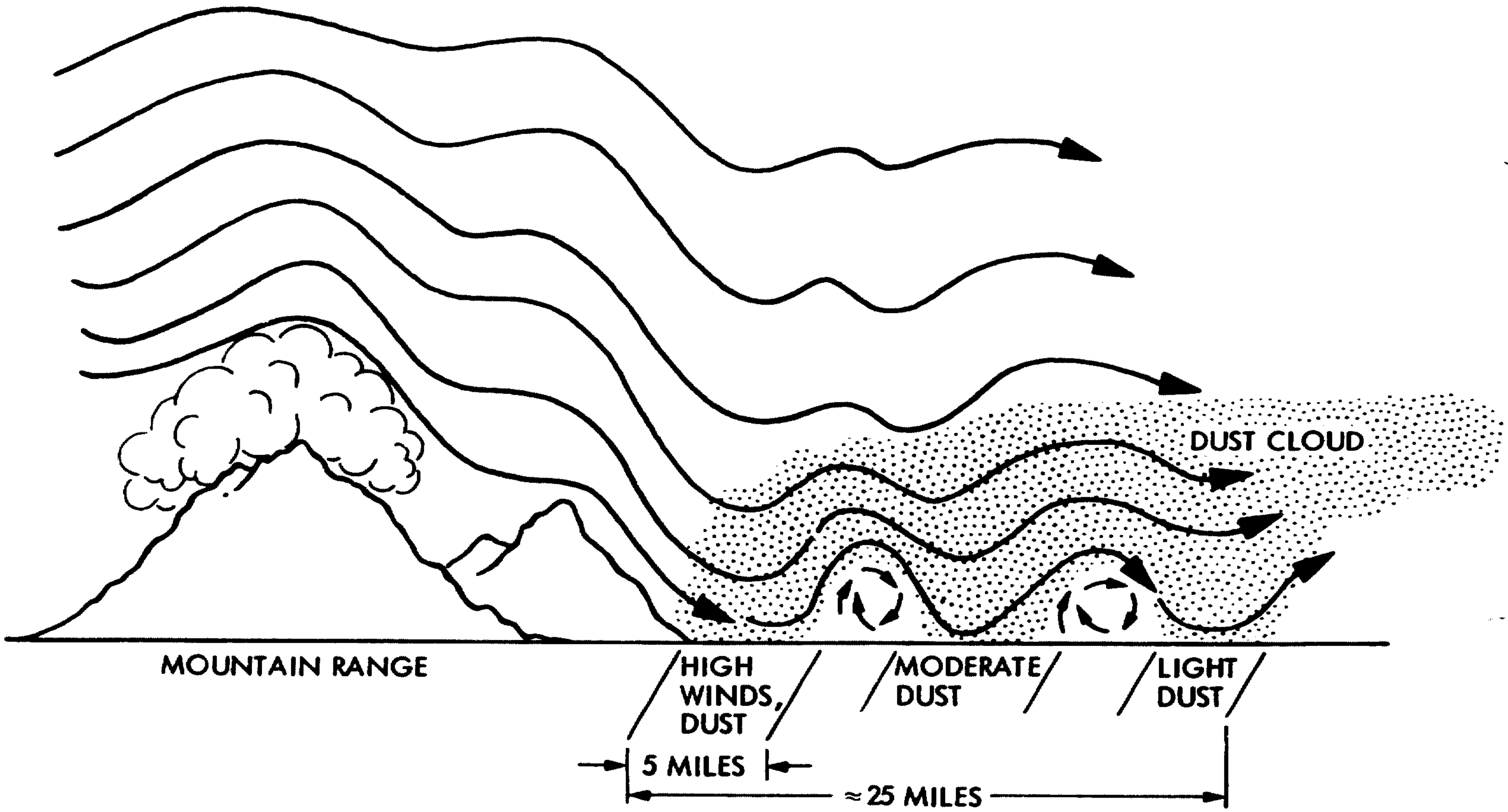

Figure 3-2. Schematic of Dust-Blow Region Produced by Severe Mountain Downslope Windstorm

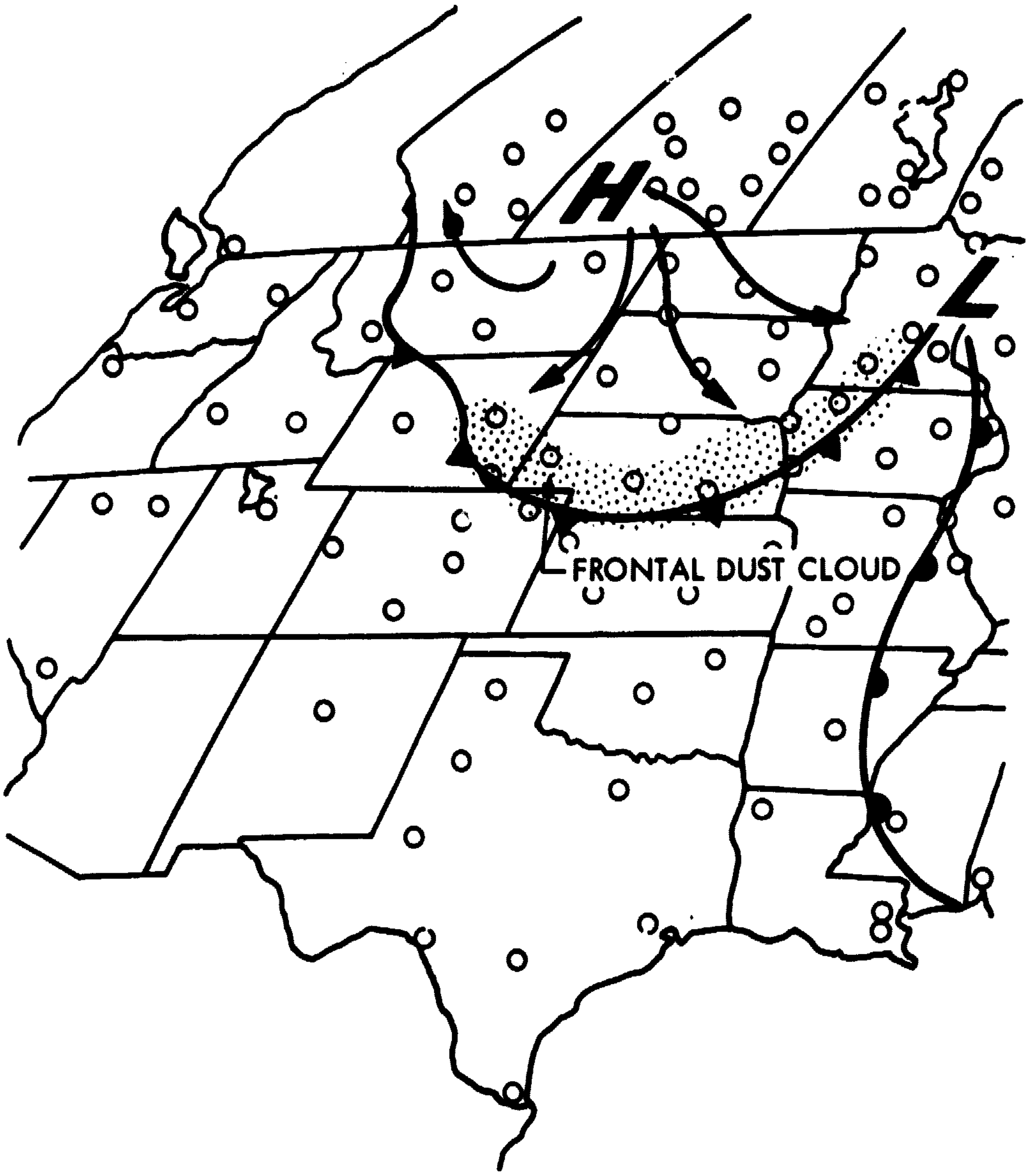

Figure 3-3. Idealized Canadian Polar Frontal Duststorm

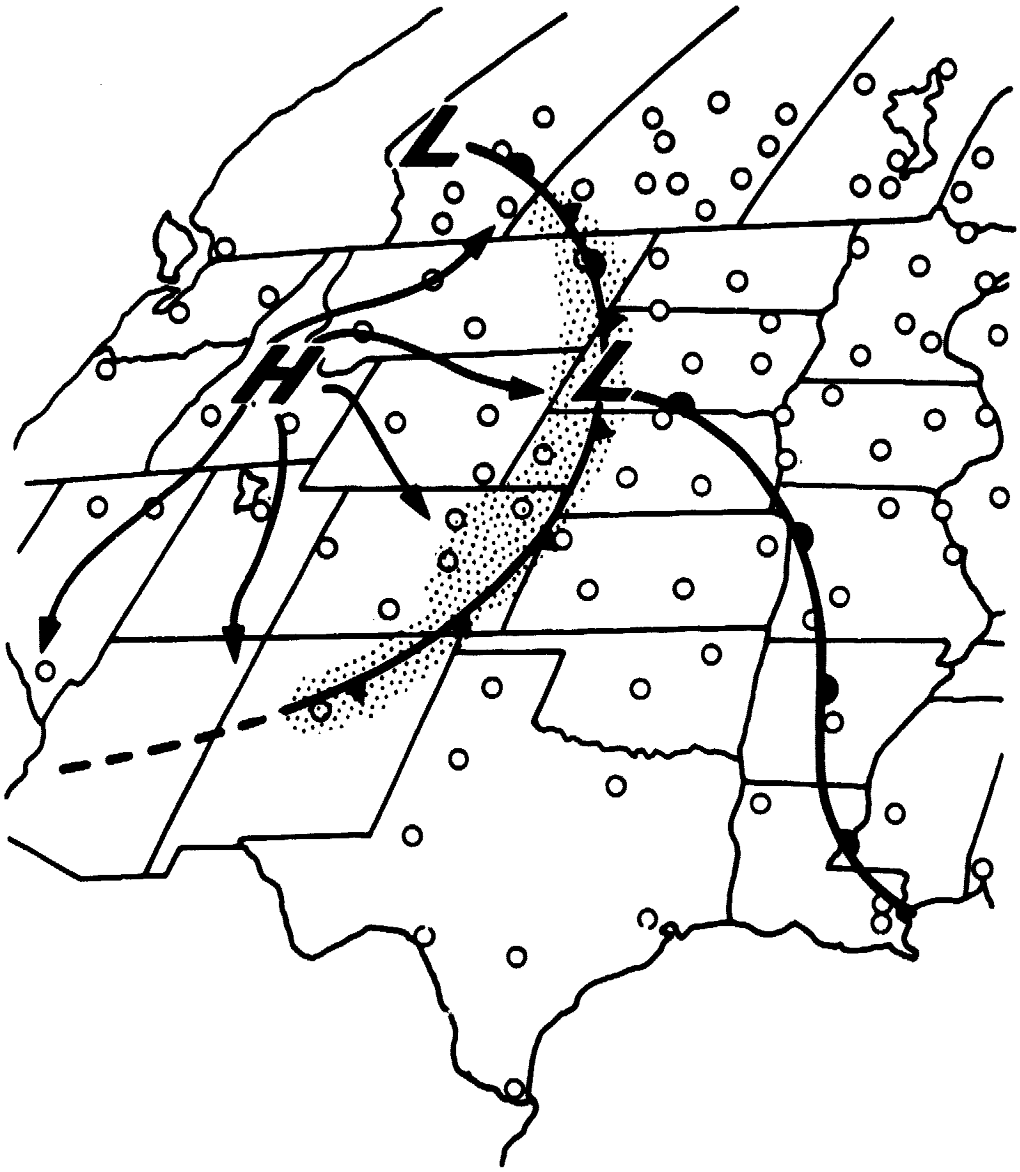

Figure 3-4. Idealized Pacific Frontal Duststorm

D. CYCLOGENIC SYSTEM

Cyclogenic duststorm systems are moderate-to-long in duration and are responsible for most of the severe soil erosion situations. Peak wind speeds frequently surpass 25 mps and occasionally exceed 50 mps. In general, these duststorms occur as a strong upper air weather system forms a rapidly deepening surface storm circulation on the Plains. Normally, these general duststorms develop as a cut-off mid-tropospheric low over the southwestern United States is forced eastward across the Continental Divide by another deep Pacific weather system moving southward out of the Gulf of Alaska (Figure 3-5). The cyclogenic or general duststorm, generally affects up to two-thirds of the Plains simultaneously and creates, in its most intense form, the worst duststorm situation possible.

The general duststorm has two to four separate duststorm producing components: the warm sector/low level jet (LLJ), the dry sector/upper level jet (ULJ), the surface storm sector, and the severe mountain downslope windstorm which was described earlier. The warm sector/low level jet component forms in the warm air sector of the developing surface storm circulation. The LLJ normally forms near the top of the boundary layer inversion within 2,000 m of the surface. As the boundary layer becomes adiabatic and surface pressure gradients intensify, both strong momentum generation and transfer occurs. Peak wind gusts may reach 25 to 35 mps from a general southerly direction. The LLJ component can produce moderate soil erosion. Figure 3-6 shows an example of a LLJ sector windfield from the April 27-28, 1975, general duststorm. The blowing dust generally occurs within the 20 mps (∿50 knots) isotach envelope on the west side of the LLJ axis.

The ULJ component of the general duststorm is operative within the dry sector which can include both hot and cool regions. Within this region, dynamic transport downward of mid-tropospheric momentum takes place producing excessive dust blows. This sector is characterized by a dry-adiabatic lapse rate from the surface to the mid-troposphere (Figure 3-7). The strongest momentum transport takes place to the right of the upper level jet stream where strong synoptic scale subsidence (i.e., dry-adiabatic warming) takes place. It is within this sector that severe erosion occurs as peak wind gusts exceed 30 mps from a general westerly direction. Figure 3-8 shows an example of the dry sector based on the April 27, 1975, duststorm. Note dust blow regions are parallel to 500 mb flow.

Outside of the dry sector, the severest soil erosion takes place within a 150 kilometer radius of the intensifying surface storm circulation. It is not unusual in this region for surface winds to become supergradient, be highly variable in direction, and exceed 40-50 mps in gusts. The surface storm circulation is dynamically driven by the approaching upper air storm. Within the surface storm circulation it is possible, and even quite likely, that more than one weather component of the general duststorm is operative and responsible for severe dust blows.

If a strong push of frigid polar air is pulled into the surface storm's circulation, an additional region of blowing dust can develop

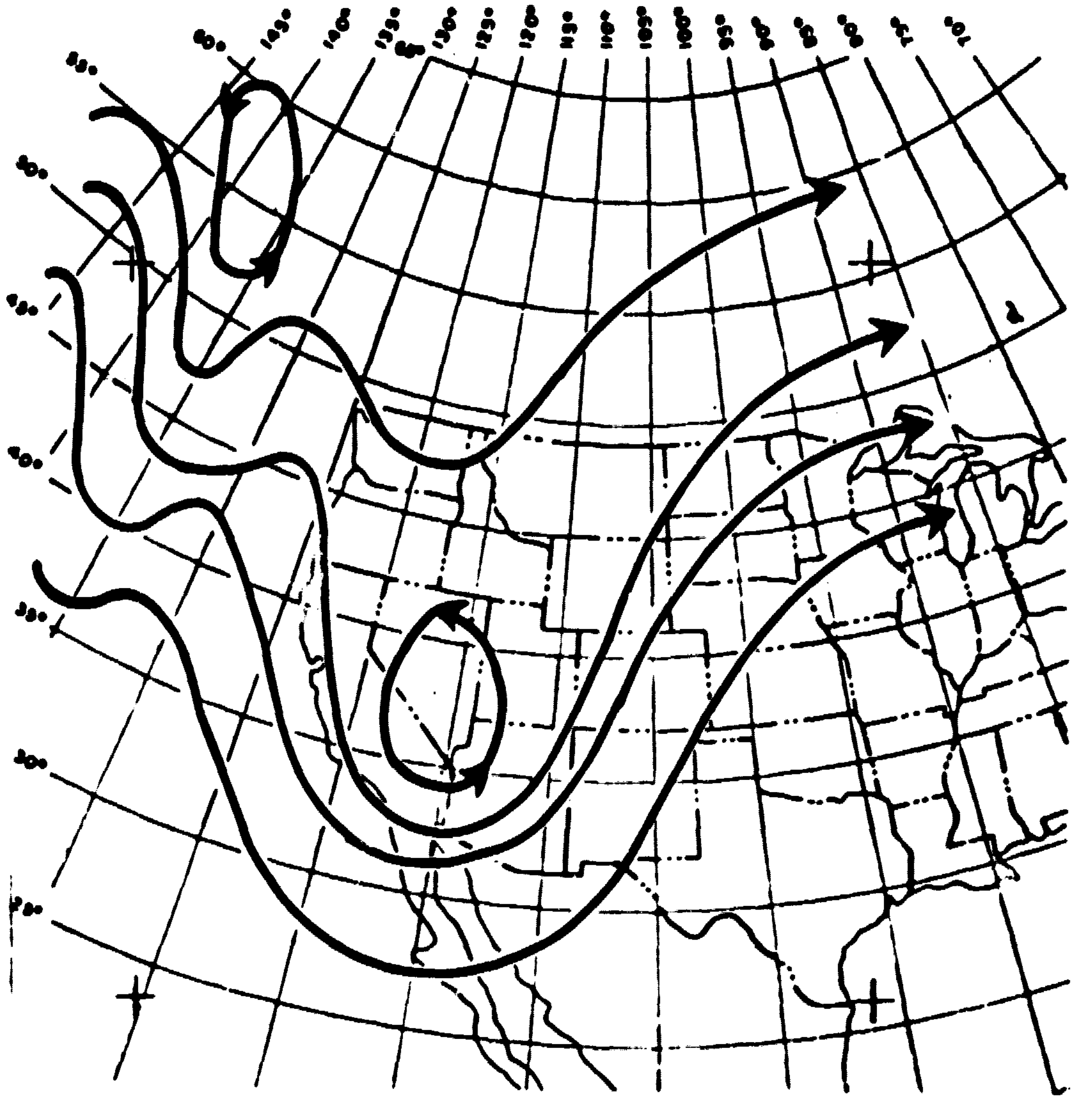

Figure 3-5. Diagram of 500 mb Flow Pattern Conducive to the Development of a Major Cyclogenic Duststorm over the Central and Southern Great Plains States

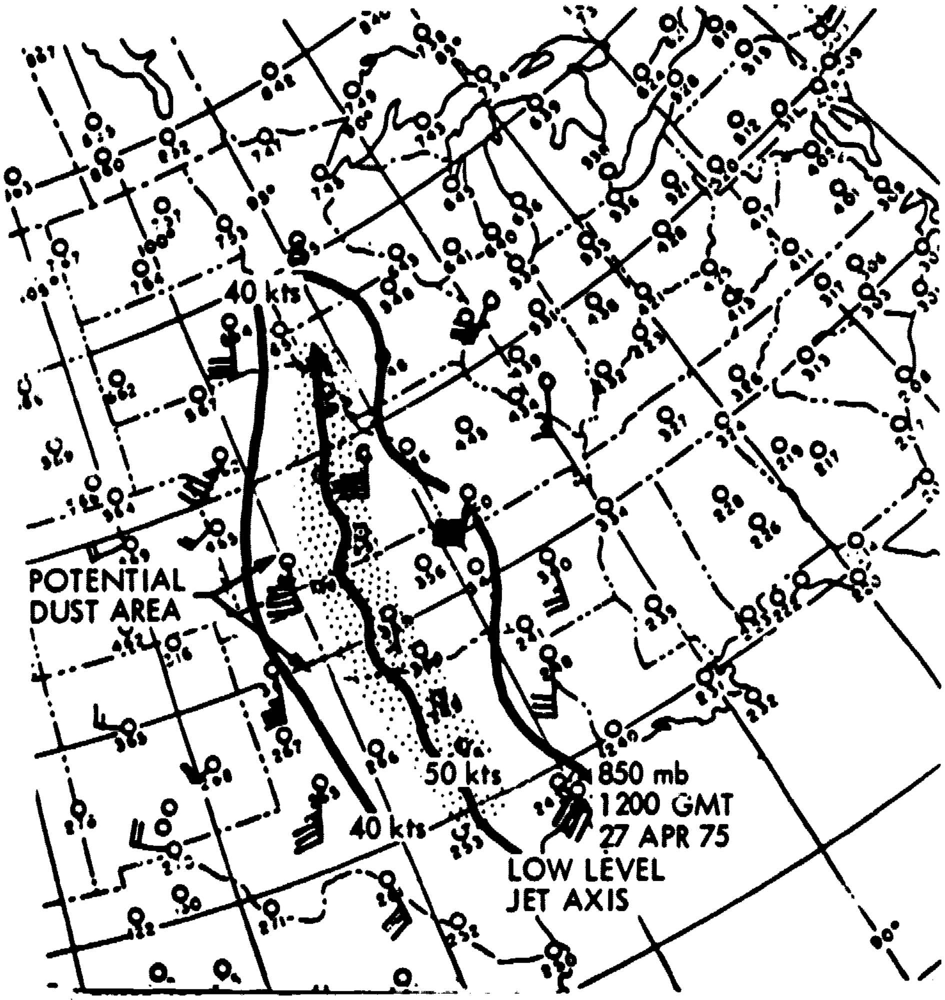

Figure 3-6. Low Level Jet (LLJ) Sector of Cyclogenic Duststorm, 850 mb, 1200 GMT, 27 April 1975. (Blowing dust region west of LLJ axis within 50 kts isotach envelope.)

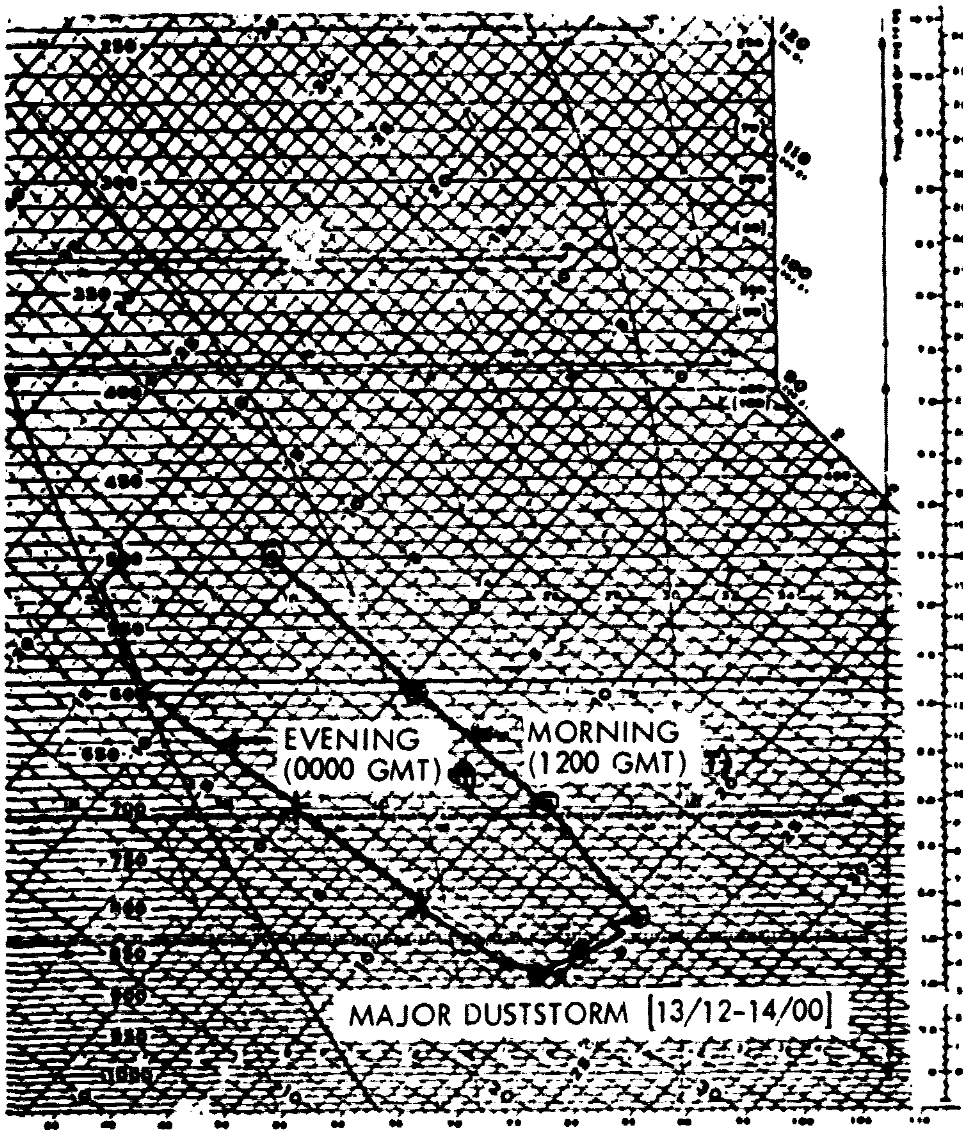

Figure 3-7. Skew-T, Log P Diagram of Surface to 500 mb Temperature Profiles for Amarillo, Texas, at 1200 GMT, 13 May 1961 and 0000 GMT, 14 May 1961. Major duststorm began at 1200 GMT, 13 May 1961, and continued to 0000 GMT, 14 May 1961. Note dry adiabatic lapse rate on evening (0000 GMT) profile.

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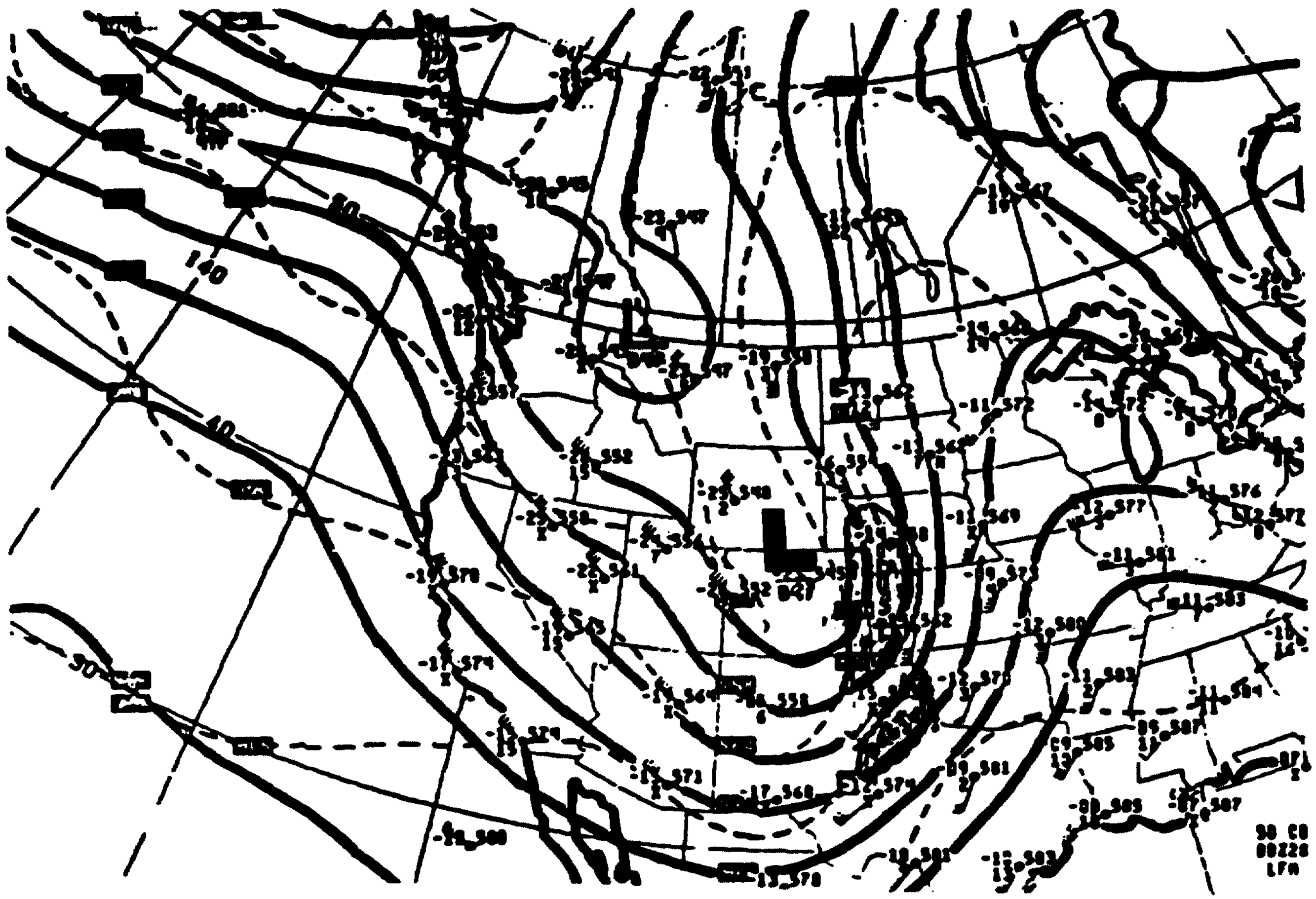

Figure 3-8. Example of Cyclogenic Duststorm Dry Sector Duststorm Relative to 500 mb Contour Flow Pattern. Date 0000 GMT, 28 April 1975. Note dust blow regions parallel to 500 mb contour field.

along the front. In this case, post-frontal winds can persist on the Plains for a longer period than if the front alone was present. Figure 3-9 shows an idealized schematic of the general duststorm and each component at its most intense stage. The severe downslope windstorm component generally precedes or accompanies cyclogenesis and occurs within the 500 mb ridge forced east ahead of the upper level system coming out of the southwest.

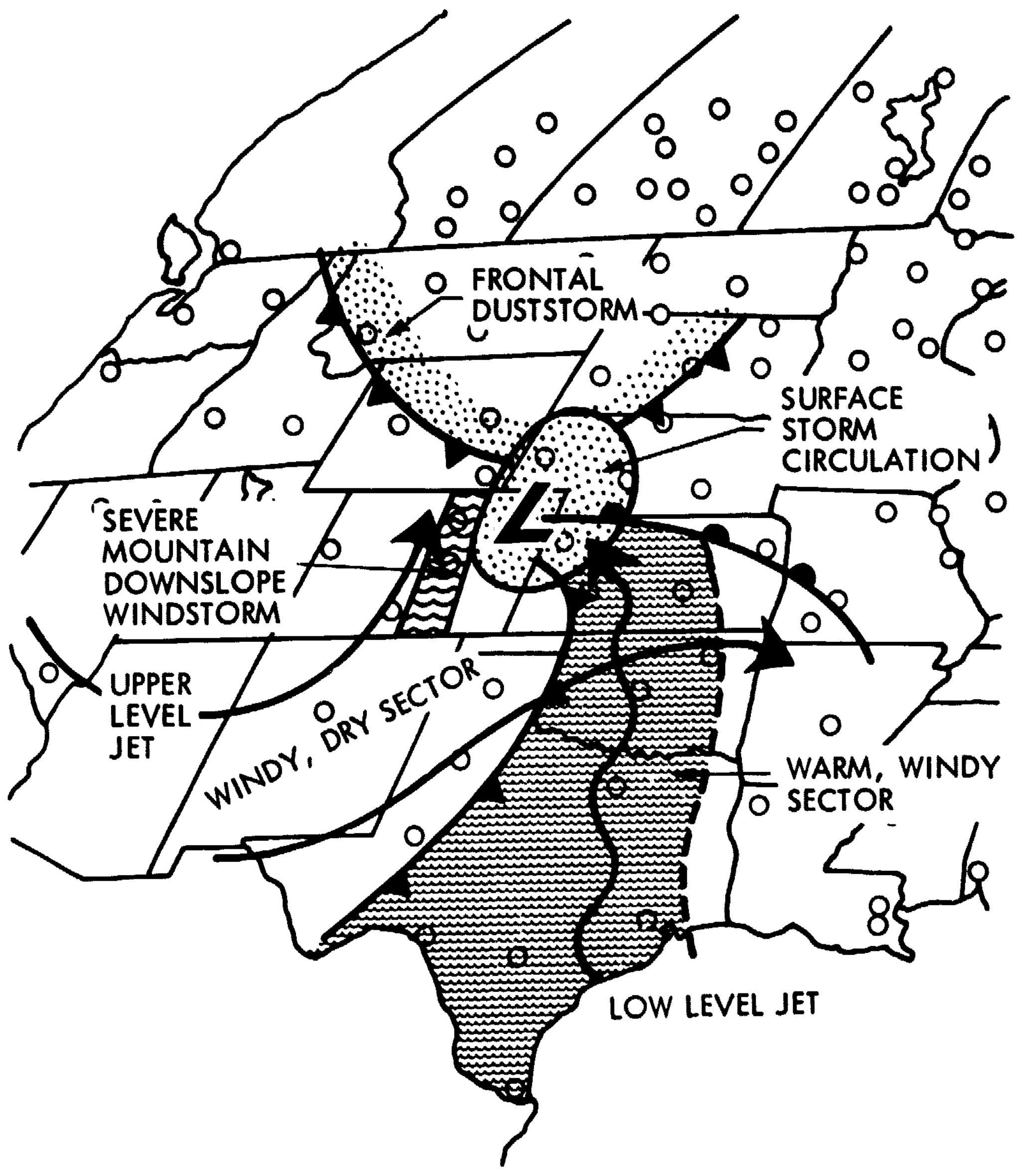

Figure 3-9. Idealized Schematic of General Cyclogenic Duststorm with Primary Sectors Identified

SECTION IV

SEVERE DUSTSTORM PREDICTIONS

Detailed study of the 50 severe duststorm dates revealed a list of frequently observed meteorological parameters. These parameters were combined into a forecast technique which was verified for the 1976-77 winter season.

A. "TELESCOPIC" FORECAST TECHNIQUE

The term "telescopic" forecast technique implies the use of a set of prediction tools which vary in use with the spatial and temporal resolution required by the forecast. Figure 4-1 presents a telescopic forecast pyramid of predictor tools used to produce severe duststorm forecasts. Seasonal range anticipation of a duststorm season is dependent on 500 mb hemispheric pattern statistics and soil rainfall history data. At longer range (3 days or more) general hemispheric flow patterns are recognized which appear related to the synoptic weather types described in the preceding section. Medium range (6-48 hour) forecasts utilize a considerable amount of special upper air analyses and computer LFM output. These analyses and numerical forecasts are blended through a man-machine mix process to obtain the duststorm forecast. The nowcast or observation forecast made relies heavily on human analysis of weather observations. This study emphasized development of a nowcast-to-medium range forecast technique.

B. SEVERE DUSTSTORM PREDICTORS

The predictors common to all 50 severe duststorm episodes listed in Table 2-2, which overlaid the duststorm region, are identified below:

(1) 850/700 mb wind ≥ 40 kts
(2) 500 mb wind ≥ 60 kts
(3) Subsidence region (LFM 12-14 hr vertical velocity field ≤ 4 kts) or (12 hr 500 mb local vorticity change $\pm 6 \times 10^{-5}$ sec^{-1}/12 hour in dry sector)
(4) Cyclogenesis location and rate of deepening (≥ 1 mb/hr)
(5) Upper/low level jet streak location
(6) Dry lapse rate region (sfc-500 mb)
(7) Satellite "comma cloud" and dust cloud patterns.

These predictors were present over the severe duststorm region for all duststorm cases presented in Table 2-2. Predictors for SMDW duststorms can be found in Scheetz et al, 1976. Figure 4-2 shows a hypothetical case where these predictors overlay a general duststorm region. Careful analyses of standard pressure level (850, 700, 500, 300, and 200 mb) charts and numerical LFM-I model output can predict the location and timing of predictor overlay regions. Satellite photos can be used to track the location of transitory short wave features or jet streaks and dust cloud "blow" regions (Anthony, 1978) in a nowcast or medium forecast mode.

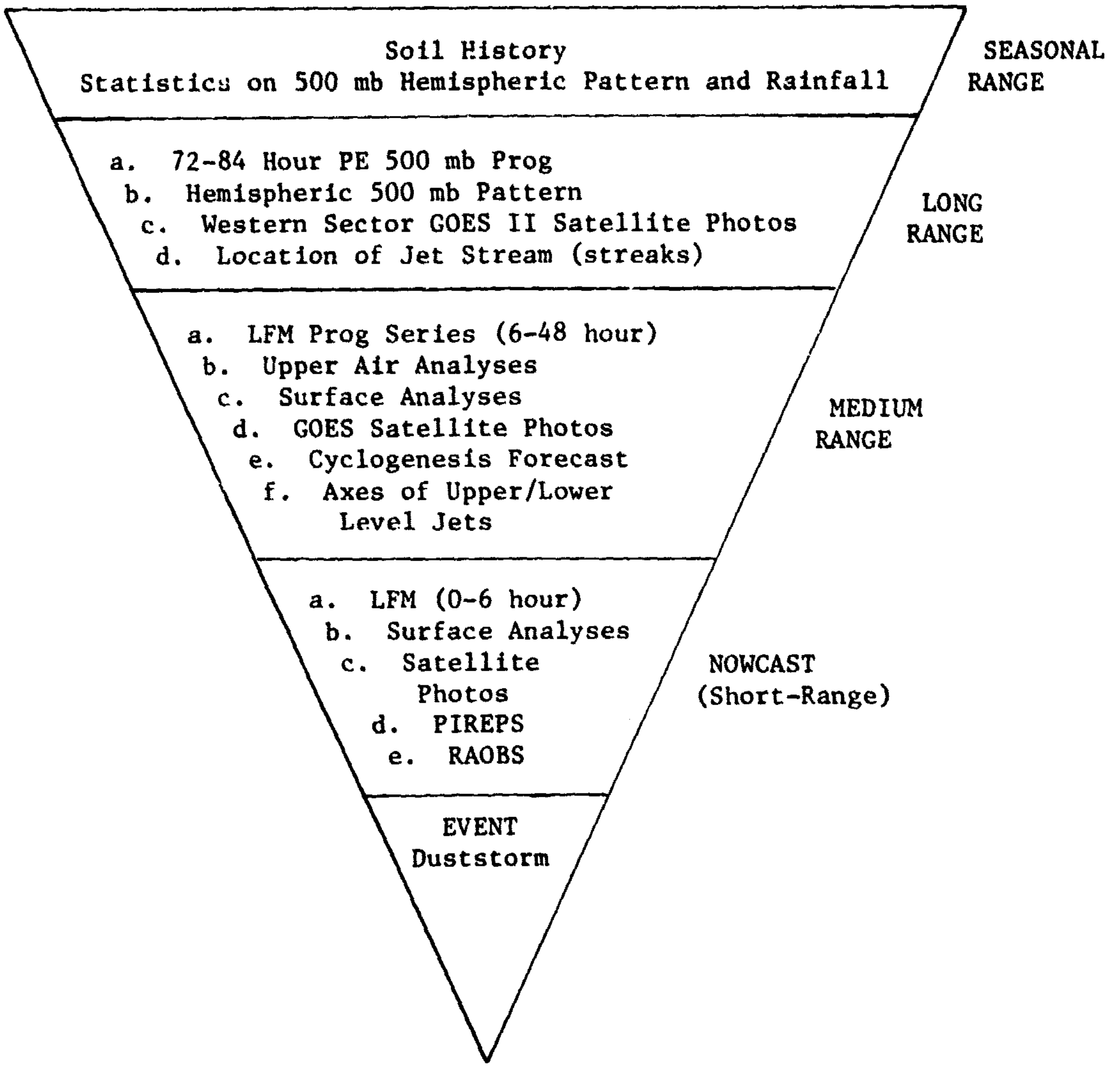

Figure 4-1. Telescopic Forecast Tools Pyramid for Severe Duststorm Prediction

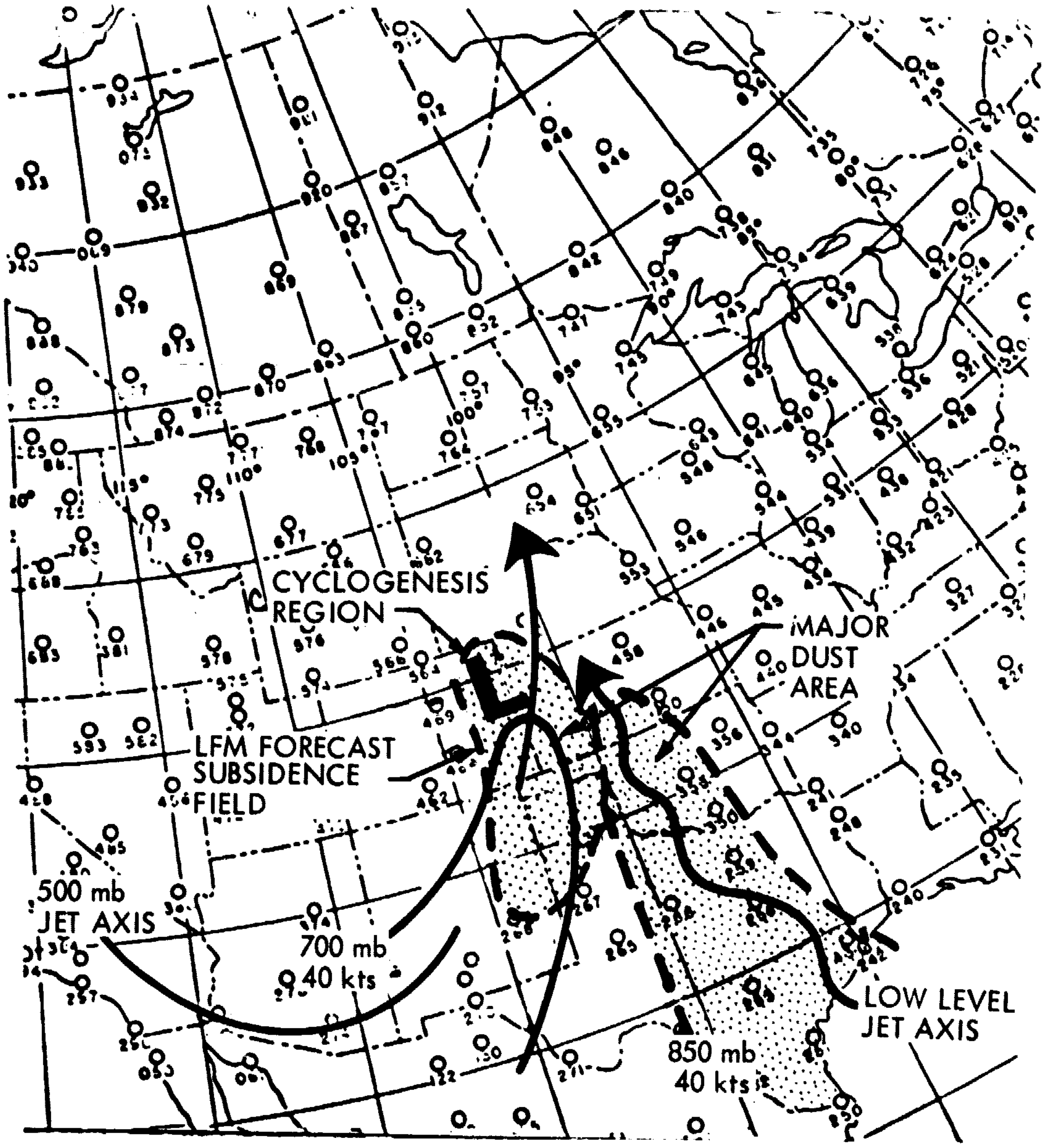

Figure 4-2. Overlay of Severe Duststorm Predictors into a Dust-Box Forecast

C. VERIFICATION

The forecast required the accurate prediction 24 hours in advance of the following duststorm characteristics:

(a) Beginning, ending, and duration times of severe dust blows.

(b) Location of severe dust blows within 100 kilometers.

(c) Peak surface gusts predicted to within 15 mps.

(d) Synoptic weather system producing the duststorm.

Two methods of prediction were tested: an objective interpretation of LFM-I prog series as received from NMC and a man-machine mix of LFM-I prog interpreted and modified by GRD meteorologists. Each forecast was phoned to both JPL and University of Wisconsin 24 hours and 6 hours in advance.

The results of the forecast verification are shown in Figure 4-3 using the technique of Donaldson et al, 1975. The man-machine mix forecast fared significantly better than the objective LFM-I forecast. The LFM forecast fields were obtained from the Bureau of Reclamation Environmental Data Network on a real-time basis. For the six severe duststorm episodes observed, the man-machine mix predicted all six correctly but predicted one non-verifying duststorm. The machine forecast technique correctly predicted only three of the six duststorms and had a false alarm rate of 60 percent. The Critical Success Index (CSI) is an indication of the ability of a forecast methodology to provide a useful, accurate prediction. The closer the CSI is to unity the better the method. The man-machine mix produced a CSI = 0.86 while the LFM's CSI = 0.38. This suggests a purely numerical approach to predicting severe duststorms produces a forecast of inferior quality to the man-machine methodology. Both techniques had problems predicting the ending time and duration of the severe duststorm episode. Duststorm durations were underforecast by 4-6 hours by both techniques.

The LFM failures were related to two specific problems:

(a) In two cases, the LFM failed to correctly predict cyclogenesis location, intensity, and occurrence. In both cases, the LFM failure was apparently related to the initial analyses underestimating the strength of the 500 mb short wave's energy (i.e., vorticity field forecast too weak) and the speed of the short wave as it approached the West Coast.

(b) Once cyclogenesis was predicted, cyclones were moved northeastward off the Plains too rapidly, i.e., the duration of the duststorm was significantly underforecast.

In both cases, tracking of the 500 mb short wave's comma cloud signature on satellite charts provided better estimates of the short wave's strength and speed. In general, the man-machine forecast technique was highly successful although refinements are needed to improve duststorm duration prediction.

Man-Machine Mix

OBSERVED \ PREDICTED	D	ND
D	x 6	y 0
ND	z 1	

D = Duststorm
ND = No Duststorm

Machine Prog

OBSERVED \ PREDICTED	D	ND
D	x 3	y 3
ND	z 2	

	MAN-MACHINE	LFM
Probability of Detection $\left(\frac{x}{x+y}\right)$	1.00	0.50
False Alarm Rate $\left(\frac{z}{x+y}\right)$	0.14	0.60
Critical Success Index $\left(\frac{x/(x+y+z)}{K}\right)$	0.86	0.38

K = 1 for duststorm

Figure 4-3. Verification of Man-Machine and Machine Forecasts of Severe Duststorms in the Central and Southern Great Plains, October 1976-April 1977 using the Donaldson et al, 1975, Objective Evaluator

SECTION V

CONCLUSIONS

A study of severe duststorms which occurred between 1968-77 was conducted to investigate the relationship of the duststorms to synoptic weather patterns. A climatology of the duststorms revealed the months January through April produced 80 percent of the storms. The primary synoptic weather causes of the severe duststorms were cyclogenic storms, frontal systems, and severe mountain downslope windstorms. Of the three causes, cyclogenic storms were the most destructive. These storms produced the severest soil erosion over a three-state or larger region for periods of up to two days. Areal coverage definitions for duststorms were developed based on the characteristics of the storms studied. A hierarchy of weather causes of severe duststorms was developed for classification purposes.

A duststorm predictability test during the winter 1976-77 was very encouraging. Man-machine mix forecasts fared significantly better than an objective numerical forecast utilizing LFM-I output. The man-machine mix forecast correctly predicted six of the seven observed duststorms with only one overforecast. The machine forecast correctly predicted only four of the seven duststorms with one overforecast. Both techniques had problems correctly predicting the duration of severe duststorms.

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